DISCUSSION BEFORE THE WIRELESS SECTION, 7TH FEBRUARY, 1940

Mr. H. L. Kirke: The paper is of very considerable interest and is the outcome of many years of theoretical study and experiment. The importance of the paper lies largely in the fact that proof of the source of scattering has been obtained. It brings out very clearly the great importance of the pulse method of exploration of the ionosphere, which has been in use for many years and superseded the original method of changing the wavelength.

The author suggests that very low-angle radiation does not penetrate the E layer, and therefore does not reach the F to get reflected back from the E layer. In this connection can the author state what is the lowest-angle radiation that can be transmitted through the E layer, and does this depend upon wavelength? This question has a bearing to a large extent on the design of transmitting aerials for long-distance communication.

Mr. R. Naismith: On page 74 the author defines scattering in terms of ionospheric structure. From Fig. 6 we see that the maximum number of these scattering clouds occur at a height of 100 km. We also know from other evidence that intense ionization occurring at 100 km. and extending over large areas is capable of effecting the transmission of radio waves of wavelengths less than 10 m. to great distances. It follows, therefore, that the small ionic clouds causing the scattering are frequently situated within larger clouds causing reflection. We can thus have on the same wavelength, at the same time, both scattering and reflection from the same place in the ionosphere. The known imperfection of the ionosphere as a medium for radio transmission implies scattering and it therefore seems unnecessary to define the term "scattering" more explicitly.

The author has made observations on the scattering of radio signals over a number of years. It would therefore be interesting to know whether he can attribute the apparently continuous production of these small ionic concentrations to a particular agent and whether their production varies during the sunspot cycle.

Mr. W. L. McPherson: The effect of carrying on a ong-continued study such as is described in the paper is to make the investigator over-emphasize the importance of the phenomena being studied, and this may be why the author is unduly pessimistic with regard to the effect of scattering on the value of highly directive aerial systems. It is well recognized that in practice the full theoretical gain of a narrow-beam aerial array is seldom realized; nevertheless, the average gain of such an aerial, taken over the useful hours for the wavelength for which the aerial is built, is sufficiently high to have considerable financial value. This is particularly the case when the beam can be steered automatically, as in the later forms of the M.U.S.A. system; and the author's arguments, if accepted, would in fact appear to constitute a reason for considering the possible extension of the M.U.S.A. principle to horizontal as well as vertical steering, rather than for discarding the principle altogether. I am not quite clear, however, as to how the author arrives at such a complete condemnation of high directivity. He states in the paper that the level of the scattered radiation is of the order of 20 to 40 db. below the primary radiation level, and this would appear to leave a normal ray of quite appreciable amplitude. I should welcome further explanation of this point.

The paper does not mention what was the state of polarization of the radiation transmitter during the pulse measurement. It would be worth while adding this information, and also any information which may have been recorded as to any peculiarities in the state of polarization of the received scattered waves.

The author states that the scattering effect increases with the wavelength, from which one might infer that on very short waves scattering is almost negligible. We cannot, however, expect that the scattering trouble will disappear altogether on the ultra-short-wave band, even although transmission does not involve reflection from the ionosphere. There is another factor to consider, particularly when we get down to wavelengths of the order of 2 m. and shorter. Tests in America lasting over some months showed that 2·5-m. communication was governed to an appreciable extent by reflection from a lower stratification in the sky, which extends over a wide area and is most clearly marked in the colder months of the winter. If reflection phenomena occur on these wavelengths one might also expect scattering. This might have some bearing on the fact that during the operation of the 17-cm. micro-ray station at Lympne there were three occasions on which the communication, otherwise perfectly good, suffered from a peculiar flutter effect. Sometimes this was audible only at one terminal, sometimes at both. Generally speaking, the signal was stable and the flutter was superimposed. There was no inter-modulation, and quality remained unaffected. A rather similar effect has also been reported in connection with the 70-cm. wavelength experiments carried out in the Mediterranean during the winter of 1931. Possibly on such occasions scattering was being caused by small clouds or patches of stratification at a fairly low level. It would be interesting to have the author's comments on this matter.

Mr. W. Ross: There are several points in the paper which call for comment, and in particular one connected with the rejection of the theory of scattering by sources on the ground. Part of the author's argument is based

on the assumption that scattering from sources on the ground would be inversely proportional to the fourth power of the wavelength. But the Rayleigh law of scattering only applies to objects very small compared with the wavelength, whereas the paper refers to scattering objects on the ground whose dimensions are comparable with the wavelength. It can be shown that scattering from terrestrial objects of a size comparable with the wavelength might be expected to reveal an intensity which increased rather than decreased with wavelength. I do not suggest, however, that this in any way detracts from the great bulk of evidence in favour of the theory that the scattering centres are in the E region.

I should welcome another expression of opinion from the author on the importance of scattering in the phenomena of lateral deviation of echoes reflected from the F layer. Some of his slides showing the bearing of the station at Dorchester received at Chelmsford revealed that the lateral deviations observed on F echoes, besides showing erratic moment-to-moment fluctuations, also showed rather long-period changes in bearing which I find difficult to explain on any theory based on scattering. I formed the impression from the author's remarks in presenting the paper, as well as from its concluding sections, that he is of the opinion that all deviations of F reflections are in some way connected with the scattering region in the E layer.

Finally, I think that as a fitting conclusion to such a long investigation on the subject of scattering some experiments should be made with a view to discovering more definitely the relative importance of scatter as compared with true reflections. There is no very great bulk of evidence yet available to show whether scattering is in fact important when transmission is being effected by normal reflection from the F layer.

Dr. R. L. Smith-Rose: I presume it is not impossible that in addition to the normal reflections a further set of echoes might be received from the first scattering source, the rays from which have subsequently suffered two reflections, one from the F layer and the other from the ground intermediately.

This paper possibly tends to destroy the first impressions created by the simple explanation of the skip distance of ray transmission. It is frequently assumed that within the skip distance there is little possibility of receiving signals from a transmitter, an occurrence which might have an obvious strategic value. The results given in this paper, however, suggest the possibility of reception within the skip distance, but it is important to bear in mind in this connection the order of magnitude involved in this work. The author shows that the level of the scattering signal is 40 db. or so below the level of the direct transmission, and he has had to use high-power transmitters in order to get sufficient intensity for recording the scattered echoes. It seems a reasonable deduction from this that, using a suitably weak transmitter, it is still possible to transmit effectively to distances well beyond the skip range with the certainty that reception within that range is too weak for reliable communication.

I should like to point out that although the author's records show these echoes from scattering sources to be very intermittent, it is nevertheless possible to receive signals sufficient for intelligible reception from broadcasting stations which are operating on the wavelengths and under the conditions described in the paper. I am not clear whether the conclusion to be drawn from that is that the reception of intelligible signals arises from a sort of integral effect of all the scattered echoes received at any time, but if so it is a little surprising that the signals received are as intelligible as they are.

I rather share with Mr. Ross the suspicion that the author has dismissed a little too easily the possibility of scattering taking place from the ground, particularly when I read his remarks to the effect that girders and trees cannot act as scattering sources. Trees, for example, can be regarded as acting as earthed aerials, and the natural wavelength of trees in this country is well within the wavelength band used by the author. It would not be expected that the scatter radiation from these trees would follow the fourth-power law which he suggests as a reason for rejecting scattering from the ground.

The author deduces that the scattering coefficient is of the order of 1/20th, and then states that the remaining 19/20ths of the radiated energy is transmitted through the layer. The fact that this coefficient is 1/20th implies that 1/20th of the energy is scattered back in a direction which will give signals at the receiver, but it does not follow that the remainder is transmitted through the layer; the whole of the 19/20ths might be scattered at random in various directions from the top of the layer.

Mr. G. Millington: There seems to be some slight misunderstanding about the difference between the "near-in" and the distant scattering, and, as I have been working under Mr. Eckersley during most of the time that this research has been going on, I should like to take the opportunity of underlining the distinction between the two types which he has described. Fig. 1, Plate 1, which shows a group of morse dots, is essentially a picture of distant scattering, in which the sharp leading edge of the scattered dot is considerably displaced from the beginning of the ground-ray dot. When we first examined these dots, we noticed that there were occasional short bursts of scattering coming in at an "equivalent height" of only about 100 km. This "near-in" scattering was much more intense than the distant scattering, and when pulses were used instead of dots it took the form of individual echoes, which were sporadic in occurrence and usually lasted for about 0·5 sec. Fig. 2, Plate 1, shows both types of scattering. The "near-in" or short-distance scattering is scattered back directly from the under side of the E region, while the distant scattering is scattered back obliquely from the upper side of the E region and is returned to the ground by reflection from the F layer, as is shown in Fig. 18.

The more or less continuous signal obtained within the skip zone from Daventry is mainly due to the distant scattering, which, although made up of a series of echoes rapidly changing in detail, is an integrated effect due to the fact that the scattering sources illuminated by the primary radiation start at the edge of the skip zone and extend a long way beyond. They thus present a large target, and they give rise to so many individual echoes, each only of short duration, that the resultant is a continuous and coherent signal.

Dr. E. H. Rayner: Is there any correlation between scattering and magnetic storms? Sometimes storms of a definite intensity, as measured by their exceeding certain arbitrary values of the variability of magnetic elements, occur once a month, and sometimes 2 or 3 months pass without any; but during the last month we have had several within a week, and it would be interesting to know whether scattering effects are linked with these conditions. Has scattering any correlation with sudden fade-outs? Does it persist after a fade-out has taken place?

How important is scattering, or its effects or causes, in relation to commercial transmission? Does it only occasionally affect the quality of the transmission?

Mr. J. A. Smale: I should like to ask what is the commercial value of the findings reported in the paper. Probably there are cases where use could be made of scattering in commercial radio transmission, but it is doubtful whether these occur sufficiently often to make it worth while. There have been a number of cases, as, for example, in communication between England and Japan on the 26-m. wave, where the maintenance of communication has been due solely to scattered signals. Cases occur where the direct transmission route is temporarily closed, communication being maintained by relay stations, and it would save a great deal of trouble and expense if we could find an alternative to the use of such relay stations.

Mr. T. L. Eckersley (*in reply*): In answer to Mr. Kirke, I would say that the lowest angle at which a signal can be transmitted through the E layer, a matter which much concerns the Empire broadcasting, is not really related primarily with scattering but with the properties of the E layer in bulk. When the critical frequency is known, the lowest angle of penetration of the E layer is also known. The presence of abnormal E, which probably has a sharply defined under-surface and which is irregular and akin to the scattering clouds, rather obscures the issue, and makes the critical frequency difficult to observe. When such abnormal E is present, it is practically impossible to specify by calculation the lowest angle of penetration. This is because it is patchy, and may or may not be penetrated even at vertical incidence. A practical point is this: from the evidence we have obtained, I do not think there is any appreciable signal beyond about 1 000 km. which has been transmitted by reflection between the abnormal E layer and the earth.

I rather gather from Mr. Naismith's remarks that he considers that the irregularities in bulk of the E-layer ionization are sufficient to account for the effects observed, and that there is thus no need to coin a new name, i.e. "scattering," for them, or to investigate them at all. Sporadic or abnormal E is an irregularity in the E region of the ionosphere and has been investigated. Yet though the scattering irregularities and the sporadic E may be akin, as suggested on page 77, there are many differences, and we cannot say that investigations under the name of sporadic E have yielded such a wealth of information about these irregularities as the investigation carried out here under the pseudonym of scattering. I would never insist that the nicely rounded spherical clouds used as a model for scattering are actually to be found everywhere in the E layer exactly to specification, yet many of the effects of irregularities in the E layer can be adequately explained in terms of such a simple model.

Although we have studied scattering throughout the period of a sunspot cycle, we are not in a position to say whether the amount of scattering varied appreciably throughout this period. Improvements in the technique of obtaining and recording the E scattering were being made all the time. Thus the observations do not form a continuous uniform series. It is therefore impossible to compare the earlier and later results. There is, however, no obvious indication that the scattering changed throughout the sunspot cycle. There is, of course, the fact that the scattered signals on Bodmin and Grimsby (both approximately 16 m.) were not heard during the sunspot minimum, but this might be attributed to the escape of these signals through the less dense layer, were it not for the fact that long-distance transmission was maintained on these wavelengths. In view of all the evidence (scattering *was* present on the longer waves), I am inclined to attribute this absence of scattering on 16 m. not to the absence of scattering clouds but to the attenuation resulting from the increased length of path over which the scattered signals had to travel.

Mr. McPherson seems to think that I have got a scattering bee in my bonnet, and that, in virtue of attending to scattering and scattering only, I have tended to exaggerate its effects. This is by no means the case. I hesitate to set down all our activities as to do so would take up too much room. I can only invite Mr. McPherson to see our records, which are by no means exclusively concerned with scattering. I think he has misunderstood my attitude towards the M.U.S.A. system. It is no wholesale condemnation as he seems to think. It was with the purpose of finding out the directional stability of long- and short-distance rays, and its relation to the M.U.S.A. system, that many of the experiments with spaced frames and scattering were initiated.

It is now well known that the ray directions vary very considerably—on Dorchester they may vary $\pm 5°$ or more, both in vertical angle and in azimuth. There can be little doubt that the main variability is due to irregularities in the E layer. Such variability is definitely a serious limitation to the use of very high directivity. Where this variability is such that no two adjacent rays can overlap, it cannot set much limitation on the use of the M.U.S.A. system. (This state of affairs probably occurs in the America–England system.) At extreme distances, for example Australia–England, the directional variability is greater than the angle between adjacent rays, and these become so inextricably mixed that it is impossible to select any one by highly directional methods. This is illustrated by the echo pattern of pulses from Australia. It is a jumble of peaks with no definite ray among them. No highly directional aerial will be of any use in selecting a single ray and avoiding selective interference effects. The limitation to the M.U.S.A. system is a matter of distance. To quote the fact that the intensity scattered back over 180° is some 40 db. down on the primary radiation is not entirely relevant. We are dealing with the case of long-distance transmissions and with energy or rays deviated over a few

degrees or so. The mechanism proposed allows the rays to be deviated over a few degrees without much loss.

With regard to ultra-short waves, I very much doubt whether the ionosphere has any appreciable effect at all. In the example of the Lympne–St. Englevert 17-cm. transmission, it seems very unlikely that a signal which has travelled 100 km. up to the ionosphere and is very weakly reflected back should appreciably affect the reception of the concentrated beam projected towards the receiver. It seems to me much more likely that the effects observed are due to irregularities in the refractive index of the lower regions of the atmosphere which have been proved to produce violent fading.*

Many polarization experiments were made, but for the sake of brevity these are not included in the paper. Transmitting aerials of various types have been used, i.e. vertical aerials, beam aerials, etc., but most of the later results on 7·59 Mc./s. were obtained with a horizontal doublet radiating vertically. This gave us about a 20 db. gain on the strength of the near-in scattering over a half-wave vertical doublet. The polarimeter was used on many occasions to measure the state of polarization of the scattered waves. The majority of such experiments have shown that the scattered signals give no balance on the polarimeter, and recent experiments using high-speed recording show that this is because the resulting polarization ellipses pass through many configurations in less than half a second.

I am glad to see that Mr. Ross and others have realized the difficulty of proving that the scattered signals come from the E layer and not from the ground. I must confess that for a long time I could find no conclusive proof and that I am still not absolutely certain that a very small proportion may not be scattered from irregularities on the ground. The main argument for believing that scattering comes from irregularities in the E layer are given in the paper, and, although singly they may not be so, when taken together they form a body of evidence which—at least to me—is very convincing. Mr. Ross's argument segregates one aspect, and perhaps for this reason carries more weight than it should. It is perfectly true that ground objects which may scatter waves are not all small compared with the wavelength, so that Rayleigh's inverse fourth-power law does not necessarily hold. In spite of this, it is very unlikely that the energy scattered will actually increase with the wavelength. This is a property of ionic clouds.

It is quite conclusive that part of the scattering comes from the E layer: the short E scattering and the location of irregular clouds in the E region are convincing proof. A wave which is wholly reflected from the E layer, i.e. which does not penetrate, would, if all the scattering were from the ground, show a perfectly clean first echo and an irregular second echo if objects on the ground were the cause of the scattering spread. Actually the first echo is just as irregular as the second, proving that the scattering irregularity is associated with the E layer and not with the ground. A great deal of accumulated evidence of this sort has convinced me that the major part of the scattered signals comes from irregularities in the E layer. The ever-present scattering from points over the sea, which is sometimes calm, shows that only an unappreciable part of the scattering can come from objects on the ground. This and other evidence constitutes the justification for neglecting the ground scattering.

Finally Mr. Ross suggests that it would be a fitting conclusion to the work on scattering if I could give an estimate of the relative importance of scattering as compared with true reflections. No doubt an evasive answer is expected, for it is difficult to give an exact meaning to "true reflection." Nevertheless, I will venture to give a numerical answer and state that just outside the skip distance approximately 96 parts of energy in 100 are true reflections, and the remaining 4 in 100 are scattered energy. This numerical description does not give a true measure of its importance. Scattering irregularities are of importance in direction-finding, since lateral deviations of the order of 4–5° are produced. They are also sufficient to mix up the rays in long-distance transmission, and the effects are, perhaps, more important than the relative energies might lead us to expect.

No doubt low-powered stations fail to afford any communication within the skip distance, and have, as stated by Dr. Smith-Rose, an obvious strategic value. Nevertheless, it would be a communication that would have to be very carefully used: a very small increase in ionic density would make a large difference in the skip distance, and it is not always easy to ensure that scattered signals should not be strong enough to be intelligible. A watch on the ionosphere would have to be kept. Stations of ordinary commercial power always seem to produce adequate signals in the skip zone, even though the scattered signals may be as much as 40 db. down on the main signals. It is only the short scattering (100 to 200 km. equivalent height) that is really intermittent. Long-distance scattering taps such a large area that signals are practically continuous, and the integral effect of all these signals produces an intelligible signal, but with a peculiar but easily recognizable timbre. Rapid flutter-fading is often produced, but even in this case the signals are usually intelligible. As stated in my answer to Mr. Ross, I do not think that ground scattering has been lightly dismissed, although a final conclusion makes it appear as if it had been.

Mr. Millington does well to emphasize the difference between short and long scattering. I think that, although mentioned in the paper itself, a further reference to it will make the matter clear and bring out the essential features of scattering.

In answer to Dr. Rayner, there is a very marked relation between bright hydrogen eruptions and scattering clouds. We have been aware of this for over two years, but have not had time or opportunity to publish the results. High-power transmissions, in which scattering clouds could be observed, only took place for four hours a week, and the probability of obtaining a fade-out during this time was small. Nevertheless, in the series of tests since 1936 there have been 15 occasions on which a fade-out occurred during the transmission period. For the activity of scattering we give a character figure 1, 2 or 3 (similar to the magnetic character figure), 3 representing

* A. R. Englund, A. B. Crawford and W. W. Mumford: *Bell System Technical Journal*, 1938, **17**, p. 489.

the most active state of the clouds. Of these 15 fade-outs, 9 were accompanied by extreme scattering activity of character 3, while of the remaining 6, 4 were less intense fades not cutting off long-distance signals entirely. Two of the fades were so intense that even the scattered signals were cut off for a period coinciding with the bright hydrogen eruption, although just before and after the scattering activity was very great. During the period 6th November, 1936 (when recording in a uniform manner was begun), to March, 1938, 11 of the 121 programmes had a scattering character figure 3. Seven of these were on the occasion of fade-outs. If the two effects had been random and uncorrelated, the number of coincidences would have been $0 \cdot 64$, which is less than a tenth of the actual number observed. Most of the programmes were observed visually, although a small part of the time was devoted to recording them. Thus we have only one photographic record of a minor fade-out, in which the F reflection was suddenly cut off and the E clouds were so much more active than usual that they almost ran continuously one into another. In at least one case the probability of a bright hydrogen eruption and a fade-out was confidently predicted on the ground that the near-in scattering was particularly active. But it is only a probability and not a certainty.

I suppose it is of some commercial and practical value to know about a partially or wholly scattered signal which is quite often made use of in actual commercial traffic. In such circumstances the scattered signal often arrives in a different direction from the true great-circle path, or it may be spread over a fairly wide angle. At such times a beam aerial directed along the true great-circle path may be of little use and better signals may be obtained on an omni-aerial, if direct reception by multiple reflections along the great-circle path is impossible and the only signals received are due to scattering. It may be of considerable value to know when such conditions occur, so as to be able to choose a suitable aerial for reception of the scattered signals. A knowledge of scattering may help us to know when a M.U.S.A. system would be profitable or not, and there are other services, such as facsimile and telephone transmission, in which it is necessary to know whether the mutilation produced by scattering is serious or not. In the latter part of his communication, Mr. Smale has quite effectively answered his own questions.